Advanced Materials Welcomed at IEDM

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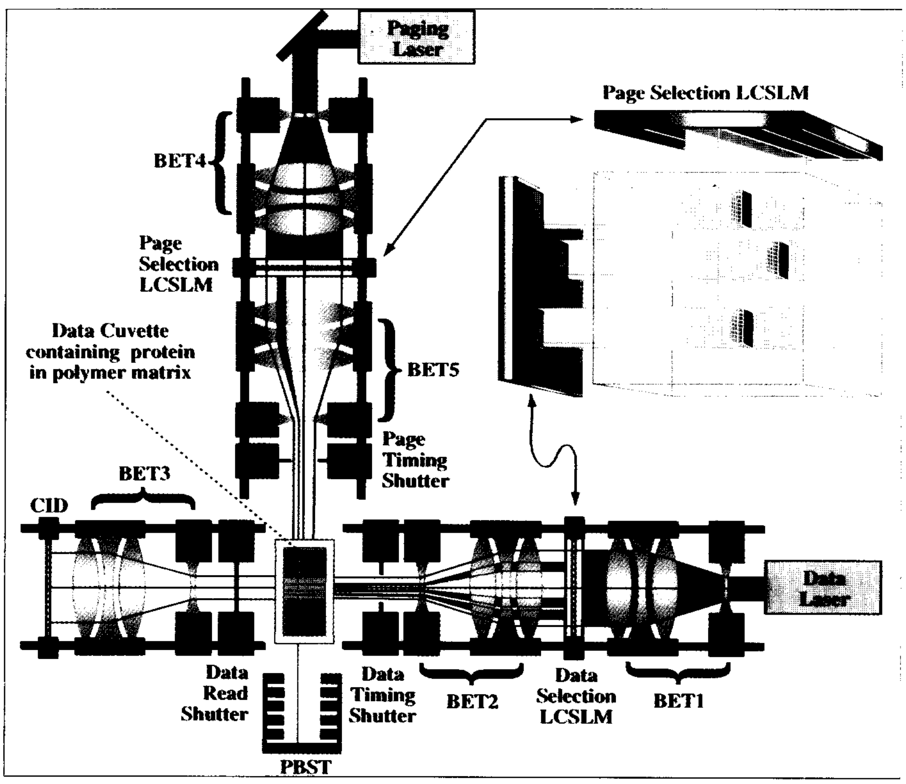
If one wants to stay on top of new trends, yet retain a proper perspective regarding how the new compounds and other advanced materials fit into the mainstream silicon world, IEDM is the event to attend. The IEEE International Electron Devices Meeting, which alternates annually between Washington DC and San Francisco, was held this year in downtown San Francisco at the height of the Christmas season. Celebrating its 40th Anniversary, IEDM displayed a lot of flash this year, and extended its traditional warm welcome towards the advanced materials.

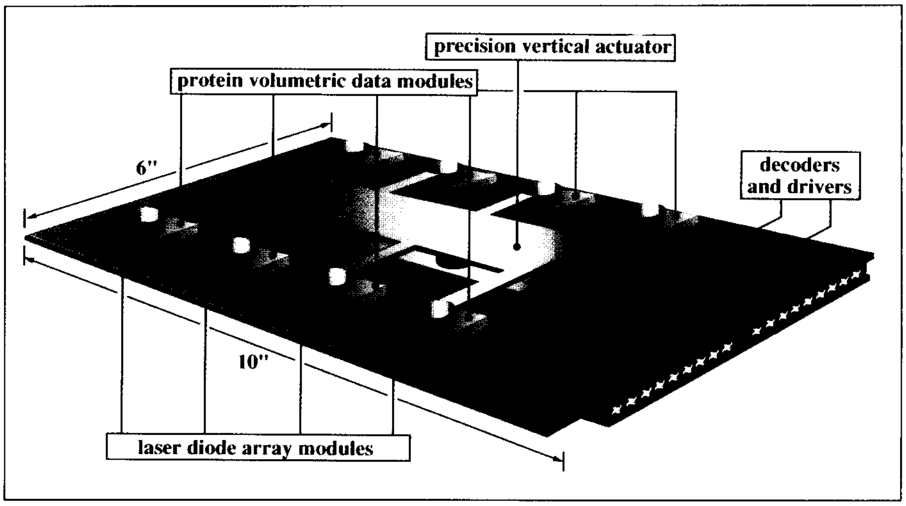
Memories stole the show, both literally and figuratively. Being the 40th Anniversary celebration, the 1994 event represented an opportunity for nostalgic historical perspective mixed with what's in store for the future. As the well-known industry author Simon Sze pointed out in his luncheon address, the challenges now faced are to overcome the 0.1 micron barrier with enhanced functionality, conquer the material limits, reduce complexity and capital cost, and increase reliability.

Professor Sze compared the past with the future by predicting that by the year 2000 silicon fabs will be at .2 micron, with 100 million components per chip, that traditional cleanrooms will move from ballroom to cluster for 300 mm wafers, and do $200 billion in business.

As to technical memory development, flash shared the main spotlight along with an especially promising laser based 3-D memory technology based on a molecular engineering that uses a protein commonly found in salt marshes, called bacteriorhodopsin. The Syracuse University findings, as reported in the keynote address by Robert Birge, could very well follow quickly on the heels of flash for next-generation optical computers and hand-held associative devices, see figures on this page.



Schematic diagram of the protein-based branched-photocycle volumetric memory under study at the W.M. Keck Center. Laser excitation is provided by using krypton-ion lasers to provide the paging and the data beams. Active matrix liquid crystal spatial light modulators (LCSLM) are used to provide page and data selection, and the branched-photocycle timing is provided by using high-speed shutters. Beam expanding telescopes (BET) are used to interface the laser beam with the spatial light modulators and a paging beam stop (PBST) is provided to prevent scattered paging light from activating proteins outside of the pages region. An additional data read shutter is included to prevent the beam from damaging the CID detector. During the read process, the data selection LCSLM is turned off completely allowing <0.06% of the light through. The resulting weak beam is sufficient to image the data onto the CID. Ultimately, the krypton-ion lasers, the beam expanding optics, the spatial light modulators and the shutters will all be replaced with laser diode arrays when a level II prototype is made.



Bacteriorhodopsin-based memory may become available on a card. This prototype would have eight memory cubes. Phased arrays of lasers would address the cubes in two dimensions, and a vertical actuator would select the page, or horizontal slice, in a cube. Such a board would store nearly 3.5 gigabytes of data. Access time within a page would rival semiconductor memory speeds, but moving to another page would require milliseconds because of an actuator's slow speed. This type of card has not been built, but one is likely to be created within a decade.

Strides in III nitrides

Especially bright interludes were provided by diamonds, SiGe, SiC and the III- nitrides. For example, Nichia demonstrated the InGaN/AlGaN double-heterostructure blue LEDs we've been hearing so much about. Dr. Shuji Nakamura, developer of the device, dimmed the lights and showed the bright blue LED, topping it with the prototype of the Japanese traffic lights using the devices, then admitted that, indeed, Nichia would "soon" announce strides in making a blue laser. Dr. Nakamura shared his most recent research that puts Nichia even more prominently in the commercial running for high volume applications by putting the nitrides closer to realizing the high quality crystals of AlGaN and InGaN, and p-type conduction in AlGaN. Characteristics of Nichia's LEDs were peak wavelengths of 450 nm, forward voltage of 3.6 V, and output power of 1.2 mW at 20 mA. The work was done by co-doping with both Zn and Si into the InGaN active layer in InGaN/AlGaN DH LEDs to increase the output power and thereby afford relatively stronger luminescence.

An American startup, ASTRALUX, INC. (Boulder, CO), working in conjunction with the University of Colorado and Boston University, under funding from the U.S. Ballistic Missile Defense Organization (BMDO) and Defense Nuclear Agency (DNA) also caused a stir. The new startup is under the direction of Dr. Jacques Pankove. With U. of Colorado's Mark Chang presenting, Astralux introduced the first high temperature high power HBT made from GaN and SiC to achieve a record current gain of 100 000, and is targeted for high power applications. The new transistors operate at temperatures up to 500°C (932°F). Applications include monitoring and controlling the performance of systems operating at elevated temperatures (automotive, diesel, and aviation engine electronics), and in space applications because of the ability to obviate the need for weighty electronics cooling systems that add so heavily to payload costs. Astralux has fabricated 35 of the devices thus far, and 7 to 10 of them actually worked!

The 1900 attendees at IEDM presented leading edge materials and device work from around the world. There were 202 invited and contributed research papers in 36 sessions, plus a full slate of short courses and controversial evening panel sessions to keep everyone busy. Featured in those parallel evening panels was, in one room, a vehement defense of hard disk memories versus the recent onslaught of flash and right next door, a rousing discussion that put defenders of GaAs in the role of the vocal minority regarding broadband and wireless communications. At one point silicon advocates in the wireless session got a bit ugly regarding the dubious contribution of GaAs when IBM's William Pence pointed out that "the reason we're giving (the cell phones) away lately is because they're full of expensive GaAs devices." Ouch!

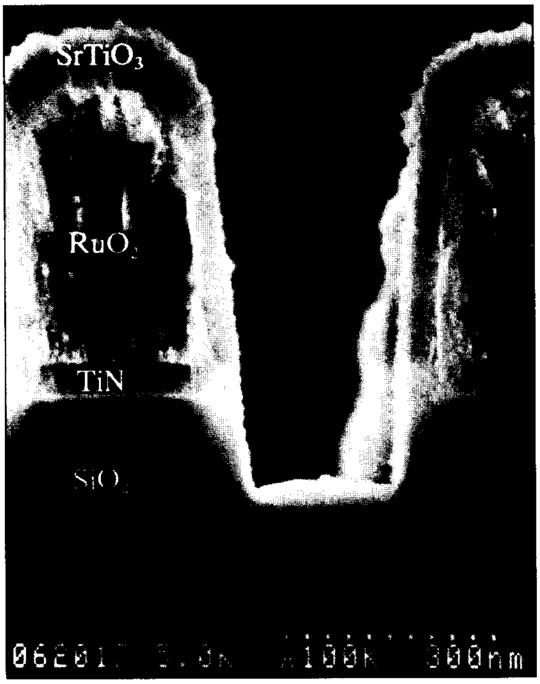
No exhibits, lots of "new" tech

As a matter of tradition and IEEE policy designed to shelter the meeting from commercial influence, IEDM does not allow exhibits, nor even literature tables, except IEEE's. The absence of exhibits, a minus to some, was obviously refreshing to the vast majority. Overall, the mood was upbeat which is quite remarkable in these times of continued severe cutbacks in R&D budgets, especially in the US.

Overall, the biggest plus of the event as it relates to non-silicon, is its traditional open-minded attitude towards showcasing "new" technology. That's where IEDM, in my opinion, has it over ISSCC, where the compounds are traditionally given very second class status, when allowed in at all. Traditionally, IEDM is where the materials scientists and device people comfortably co-exist, whereas ISSCC matches the leading edge device science with potential systems integrators. ISSCC had only 4 papers on what the silicon world still classifies as "exotics" whereas IEDM had almost a dozen well-attended sessions devoted to the growing variety of compounds.

Vacuum electronics

When looking through the cumbersome proceedings (almost 2 inches thick, weighing nearly 5 pounds) the number of papers devoted to the subjects covered in *III-Vs Review* is staggering. Three sessions were on vacuum electronics. The first dealt with cold-cathode electron emitters, with applications aimed at flat panel display, fast gated emitters (field emitters and ferroelectric), and various microwave devices. The second presented several novel fast wave devices for applications such as fusion, drivers for high-energy accelerators, and sources for high power radar systems and materials processing. The third covered linear beam devices with a familiar roster of III-



The first practical capacitor structure for gigabit-scale DRAMs (dynamic read-only memories) is described in, "A Gbit-scale DRAM stacked capacitor technology with ECR MOCVD $SrTiO_3$ and RIE patterned RuO_2/TiN storage nodes". (Paper #34.1, Lesaicherre et al. NEC). A high dielectric constant $SrTiO_3$ film is used on the storage electrode sidewalls. It features a storage capacitance of 25fF, using 0.5μm-high stacked storage electrodes in a 0.125μm capacitor area, and low leakage current densities.

Vers presenting some of the latest experimental results on linear beam microwave amplifiers and oscillators as well as current achievements in device performances.

SiGe

SiGe was the hottest topic in Si circles this year and IEDM accepted seven papers on SiGe from a variety of joint university/corporate teams. Several papers describe SiGe's use in building MOSFETs for logic and tunnel diodes for SRAMs and the IBM/Analog Device team pushed beyond their fast analog ICs of last year by also addressing RF IC application.

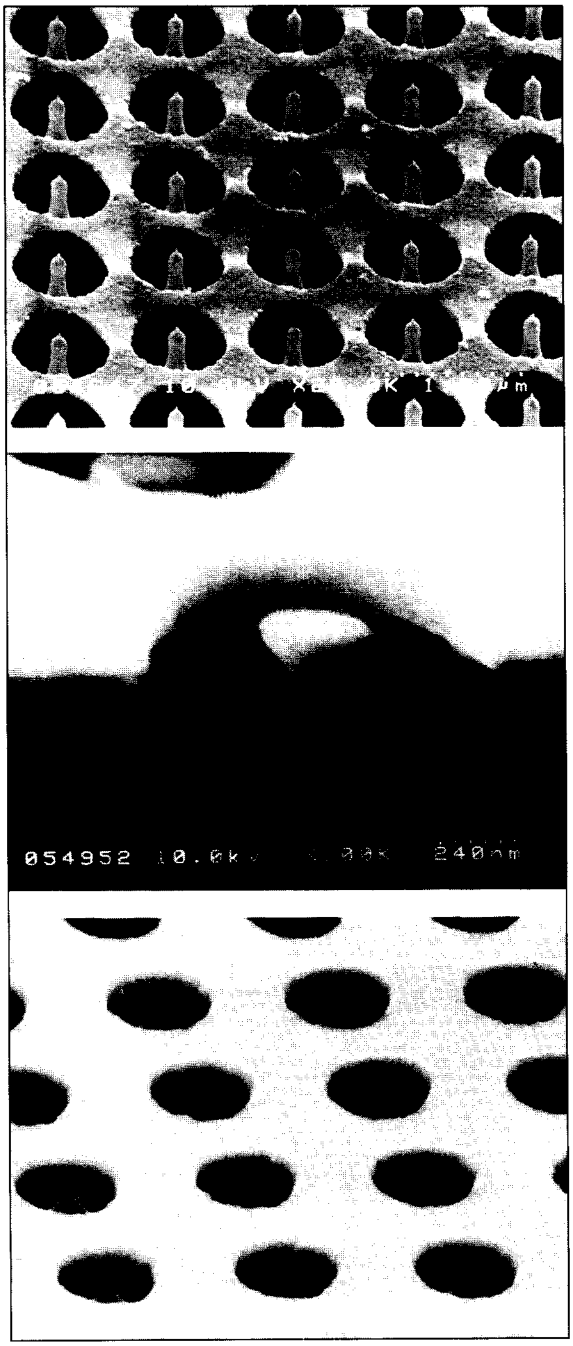
A team from Daimler Benz and the University of Ulm in Germany reported on SiGe power HBTs also aimed at RF applications. In contrast, a UCLA team presented a novel high speed, compact memory cell for SRAMs based on a bistable GeSi/Si tunnel diode.

III-Vs

Four sessions were devoted to the more familiar III-V areas categorized as Quantum Electronics and Compound Semiconductor Devices. Under new HBTs, the following were reported: Stanford University and Toshiba with a pnp AlGaAs/GaAs HBT with a 37 GHz cut off frequency, Texas Instruments with a carbon-doped HBT bias stressed at elevated temperatures, and Fujitsu Laboratories with a high reliability InGaP/GaAs HBT fabricated by a self-aligned gate process (activation energy of 2.0 eV and time to failure of 10^6 hours at a junction temperature of 200°C). Fujitsu also reported progress on their 3.5V 1W high efficiency AlGaAs/GaAs HBTs with collector launcher structure for the next generation power amplifier market that will require high output power at low voltage. NEC reported the first power application of AlGaAs/GaAs HBTs with selective regrown extrinsic base layers using ultra-high carbon doping, and Martin Marietta Laboratories (EP-3 in Syracuse) reported a benchmark X-band AlGaAs/GaAs HBT MMIC power amplifier with 7 W output power using a novel flipside "bathtub" as the heat sink.

MODFETs & APDs

In addition to Nichia's reporting in the Photonic Devices session, a team from IBM, Stanford and Litton reported direct measurement of transit time effects on a device fabricated on a GaAs/AlGaAs MODFET wafer. Also in that session, Canada checked via Simon Fraser University and Bell-Northern Research reporting investigations of breakdown voltage and its temperature dependence from -40°C to 110°C in SAGCM In P/InGaAs avalanche photodiodes. The final session on Quantums and Compounds dealt primarily with progress



The top photo is a scanning-electron microscope (SEM) view of a so-called "tower" cathode structure, where field emission was demonstrated at about 8 volts, the lowest gate voltage for silicon field emitters ever reported. The aspect ratio of the emitters is about 6, and their diameters are 0.15μm.

The middle and bottom SEM photos illustrate a so-called 'cocktail-glass' structure. The middle photo shows a silicon emitter structure where the angle of the planes is fixed by 331 planes. The bottom photo shows a field emitter array with a gate diameter of about 0.5μm. The researchers report they observed field emission under 14 volts, the lowest gate voltage for lateral-structure silicon field emitter arrays ever reported.

in HEMTs from Japanese companies; Hitachi Central Research Labs introduced the first high performance InAlAs/InGaAs HEMTs lattice-mismatched on GaAs that are comparable to, if not higher than those grown on lattice-matched InP substrates, boasting an oscillation frequency of 147 GHz. Hitachi also reported on a 2V operation PHEMT with 6.2% power-added efficiency suitable for use in analog and digital cellular phone systems. NEC described a high efficiency 6.6W 12 GHz GaAs-based heterojunction FET for Ku-band, and Fujitsu reported on a 3.6 GHz dual modulus prescaler IC fabricated on a 0.35 micron Si-doped InAlGaAs/AlGaAs HEMT on a Si substrate.

InP HEMTs

The Americans, not to be outdone-came in with an extremely low noise InP based HEMT with Si nitride passivation as reported by Martin Marietta Labs in Syracuse. At 63 GHz the 0.1 micron gate length passivated HEMT (InAlAs/InGaAs on InP) had a minimum noise figure of 0.8 dB and an associated gain of 7.6 dB.

Stanford University's Center for Integrated Systems reported the accurate modelling of GaAs MESFET sidegating effects by trapping simulation, and in a late paper on HEMT development, from the Fraunhöfer Institute in Freiburg and Telekom Research in Darmstädt reported on the first 1.3 micron monolithic optoelectronic receiver using InGaAs MSM photodiode. The AlGaAs/GaAs HEMTs were grown on GaAs.

Dwarfing GaAs

In the opinion of many who make the US meeting circuit, IEDM obviously isn't just a silicon meeting and it dwarfs traditional GaAs meets like the GaAs IC Symposium and MANTECH which, because of their paltry attendance of late, look more like workshops with exhibits. IEDM even gives MTT a run for the money. In this era of less funds for too many meetings, and far too many papers, is the IEEE over-saturating the industry?

As we head into a new era where the cry is to broaden one's perspective, become less entrenched, and better integrate technologies, meetings like IEDM offer relief from tunnel vision.

As mentioned above, IEDM trades off between San Francisco and Washington each year, and next year's meeting will be held in Washington DC, 10-13 December, at the Washington Hilton.

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